

Planetary Protection Stability Assessment of Dawn's End-of-Life Orbit at Ceres

Dan Grebow, Marc Rayman

42nd COSPAR Scientific Assembly

Pasadena, CA

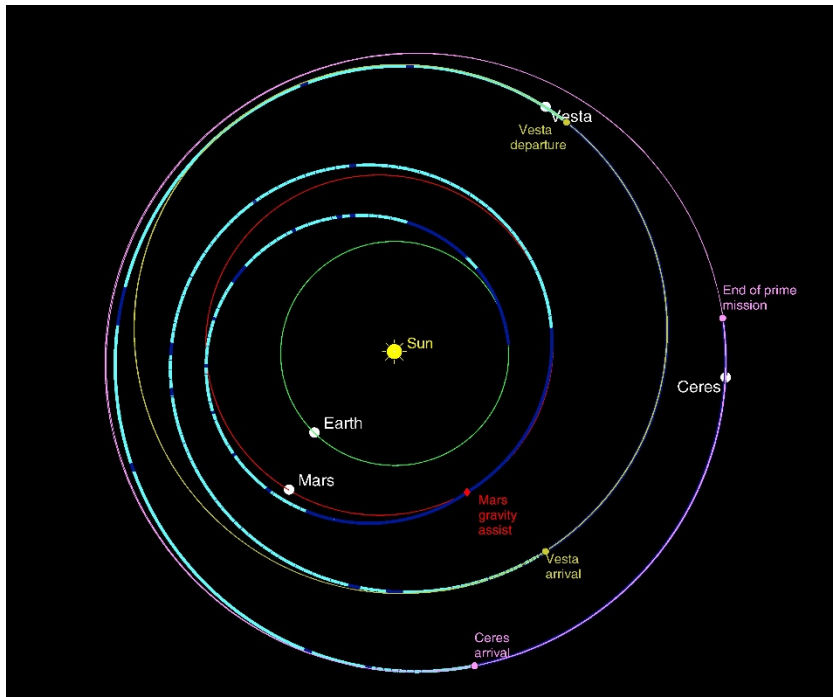
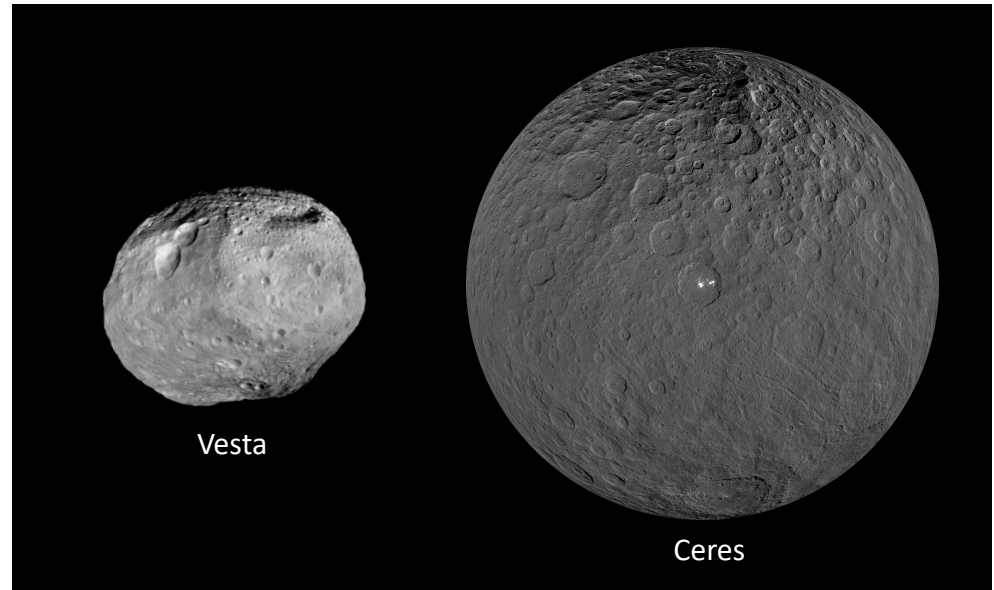
July 16, 2018

UCLA



Dawn: NASA Discovery Mission

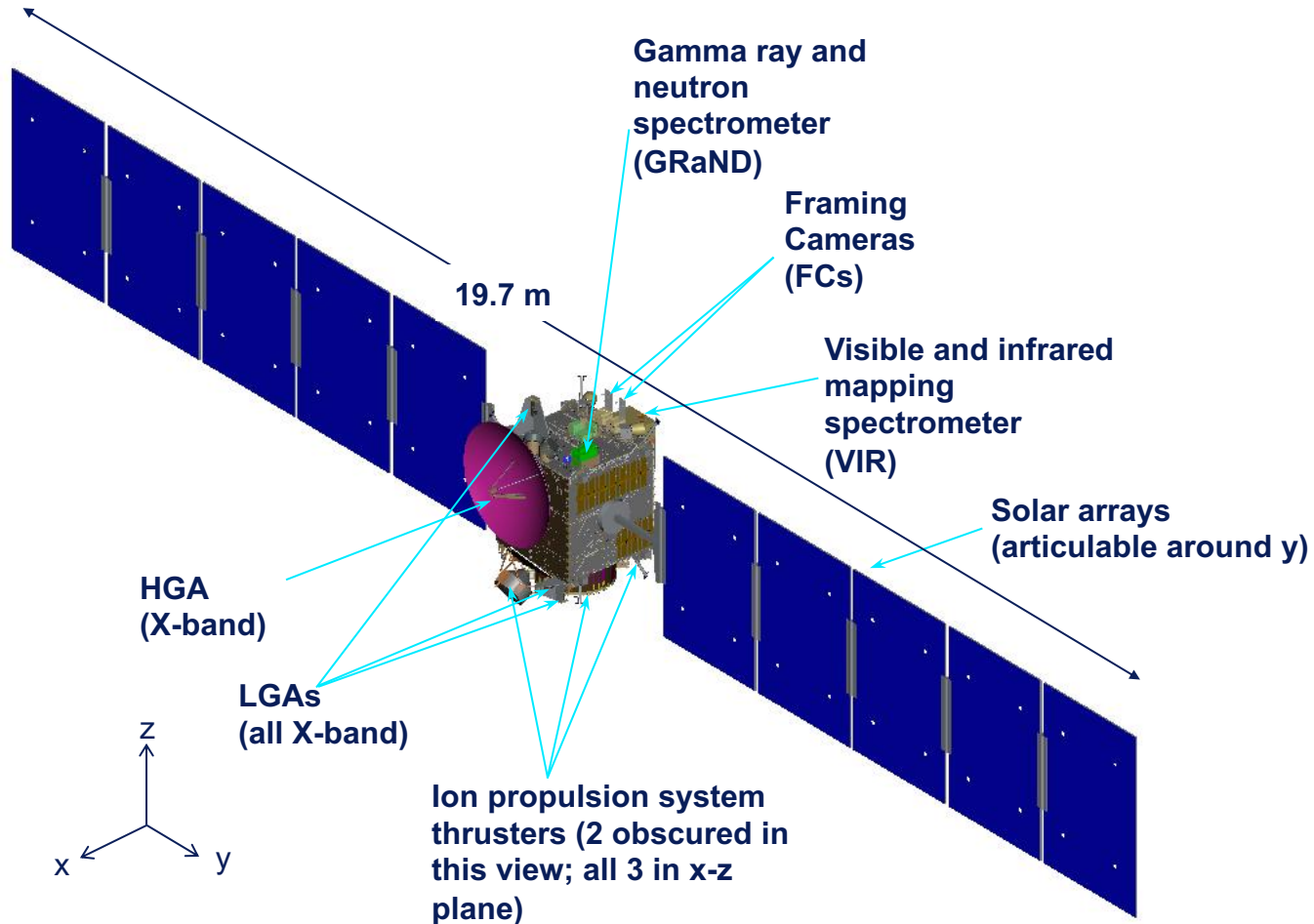
- Increase understanding of physical and chemical conditions and processes acting during solar system's epoch of planet formation
- Investigate two largest objects in main asteroid belt: Vesta and Ceres
- Orbit Vesta and Ceres acquiring imaging data, spectra, and gravity measurements



Dawn Mission Overview:

- Sept. 27, 2007: Launch
- Feb. 2009: Mars gravity assist
- May 2011 – Sept. 2012: Vesta campaign
- March 2015: Ceres arrival
- June 30, 2016: End prime mission
- July 2016 – Oct. 2017: XM1
- **Oct. 2017 – ~Oct. 2018: XM2**

Healthy Dawn Spacecraft



Loss of three of four reaction wheel assemblies does not limit attitude control
Full attitude control provided by RCS

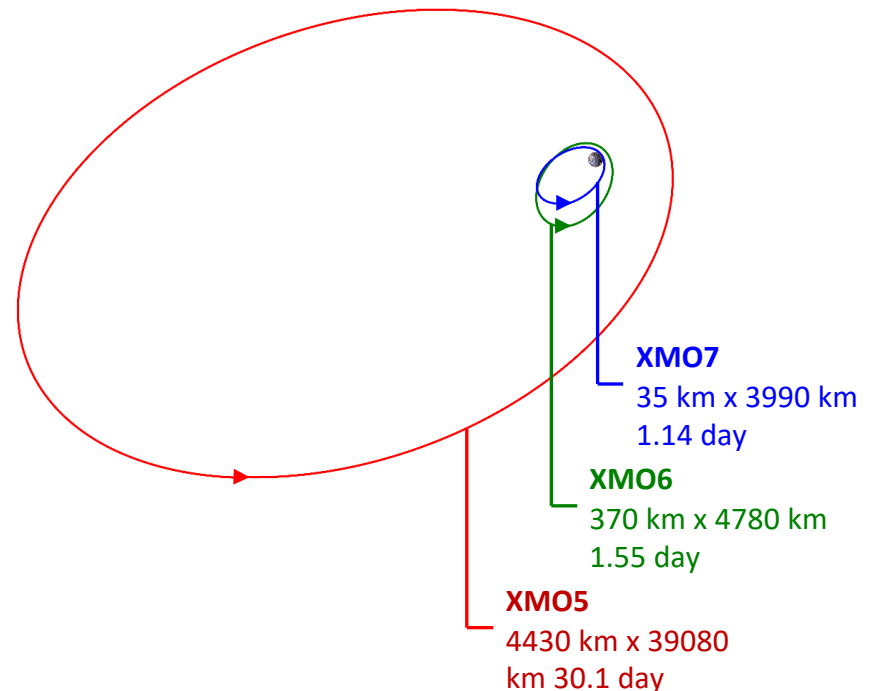
Second Extended Mission (XM2)

Objectives

- Test hypotheses of Ceres' origin and evolution
- Investigate possibly unique cryomagmatic sources and processes at Occator Crater (as well as other sites)
- Quantify current outgassing rate and cause

Mission Architecture

- Three science orbits: XMO5, XMO6, XMO7
- Four-week IPS transfer to XMO6 started April 17, 2018
- 17 days in XMO6
- One-week transfer to XMO7
- TCM ensured peridemeter over Cerelia Facula June 23 and 24
- Remain in XMO7 until hydrazine is exhausted and spacecraft attitude can no longer be controlled



Dawn's Final Orbit (XMO7)

Orbital parameters:

Period = 27.2 hr

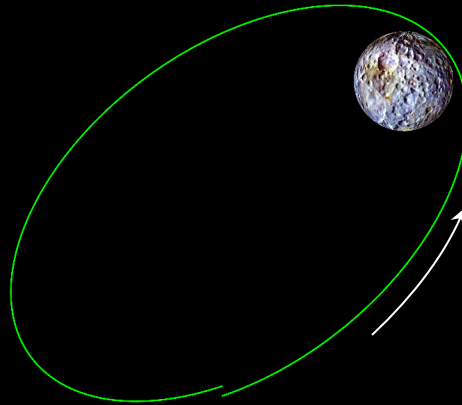
Eccentricity = 0.8

Inclination = 84.3°

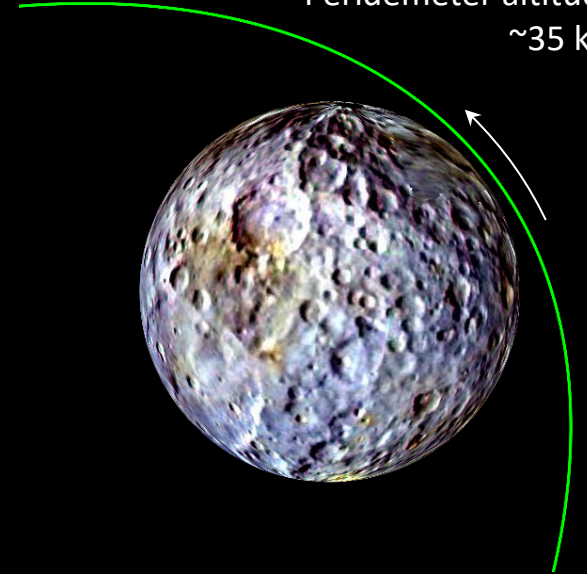
Initial Beta = 27.1°

Peridometer 13 and 14
designed to fly over
Cerelia Facula

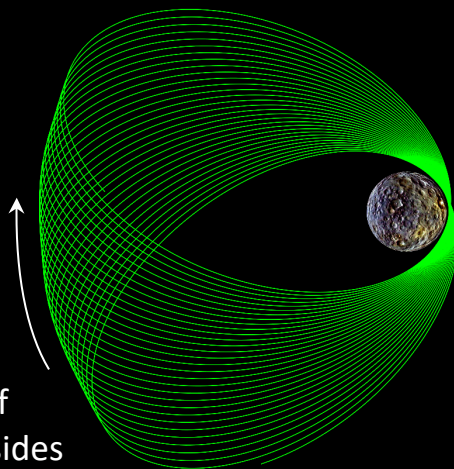
3:1 resonant orbit



Peridometer altitude
 ~ 35 km



First 30 science orbits



Natural
rotation of
line of apsides

- J2 (measure of Ceres oblateness, large for Ceres) causes line of apsides to rotate 1.7° per day
 - Periapsis latitude shifts 1.9° per orbit
 - Periapsis never directly over same place
- J2 stabilizes solar gravity perturbations
- End-of-Mission occurs in this orbit when spacecraft runs out of hydrazine for attitude control (CBE October 10, 2018)

Planetary Protection Guidelines

- Category III flyby mission due to Mars flyby
- No Flight System requirements
- Mars impact in accordance with NPG 8020.12B
- Avoid impacting Vesta
- Demonstrate 20-year Ceres orbital lifetime

“The Project will provide a spacecraft orbital lifetime around Ceres of greater than 20 years post-orbital-insertion, based on the worst-case credible gravity field model.”

- excerpt from Dawn Planetary Protection Plan (JPL D-25850)

- Report on biological interest of Ceres as obtained by scientific payload
- Prepare end-of-mission PP report

Orbital Lifetime Analysis

The Dawn projected elected to provide significant margin on the 20-yr requirement

- XMO7 designed to ensure lifetime exceeds 50 years with 99% confidence
- CBE end-of-mission (~3.5 years post orbit insertion) is starting point for lifetime analysis
- Spacecraft assumed to be unmaneuverable during lifetime analysis

Approach to Compliance

Propagate trajectories 50 years into the future with Dawn flight software Mystic (Greg Whiffen)

Force Model

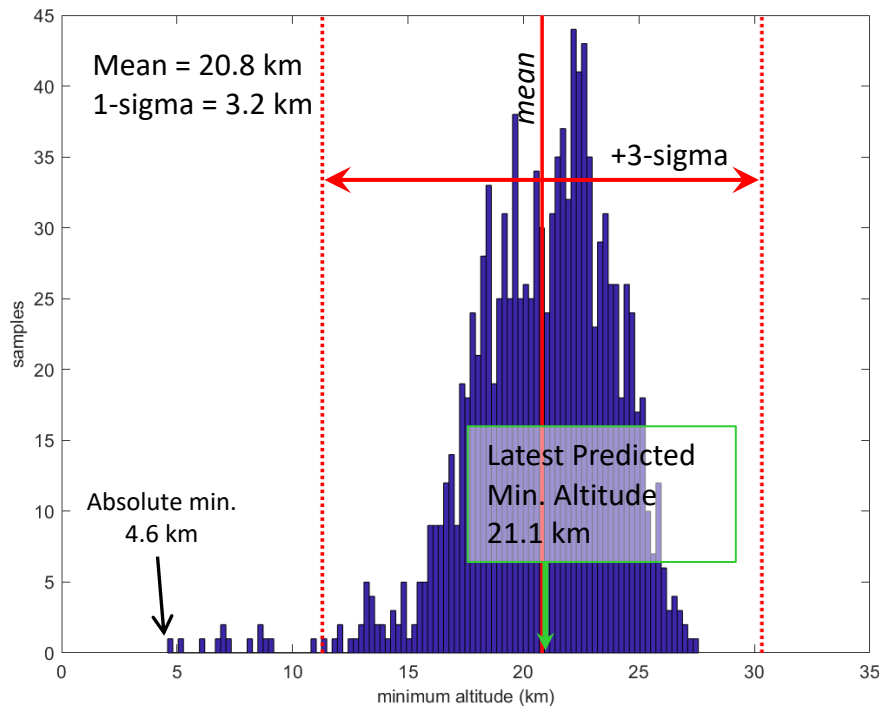
- Sun, Planets, Moon, and Pluto point-mass gravities
- Best Ceres 18x18 science gravity field
- Flat plate SRP model for bus and arrays, conservative because tumbling spacecraft

Monte Carlo Uncertainty

- **End-of-mission state dispersion:** RCS thruster activity during science operations
- **Ceres gravity:** conservatively sampled by inflating uncertainty by factor of five for harmonics less than degree and order 4, otherwise by factor of two
- **Ceres topography:** shape model conservatively inflated by 3-sigma or 300 meters, whichever is greater

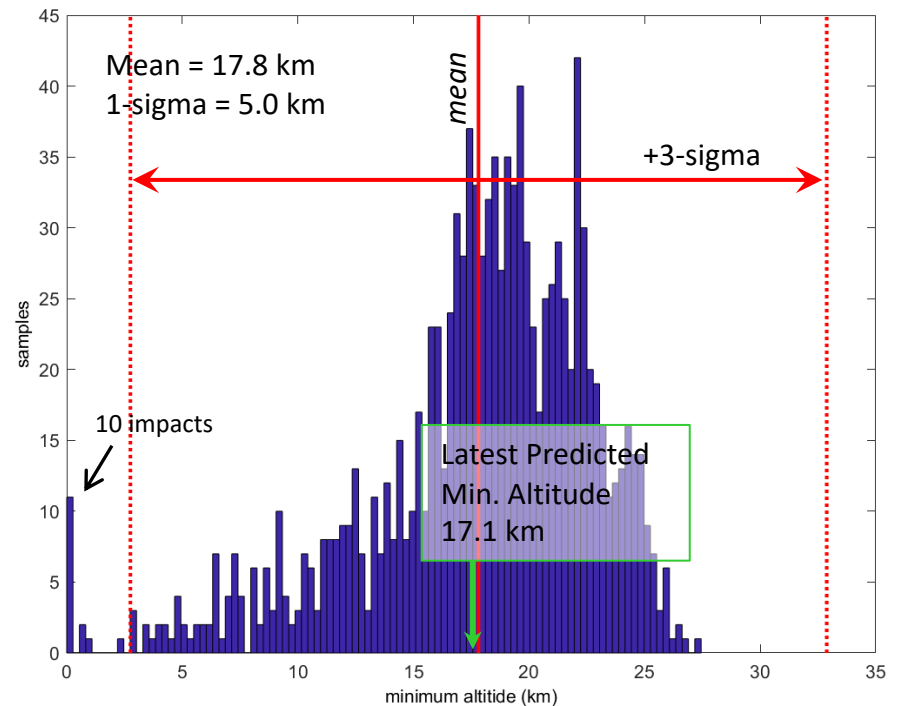
Histograms of Minimum Spacecraft Altitude from Ceres' Surface

20-year Monte Carlo Study



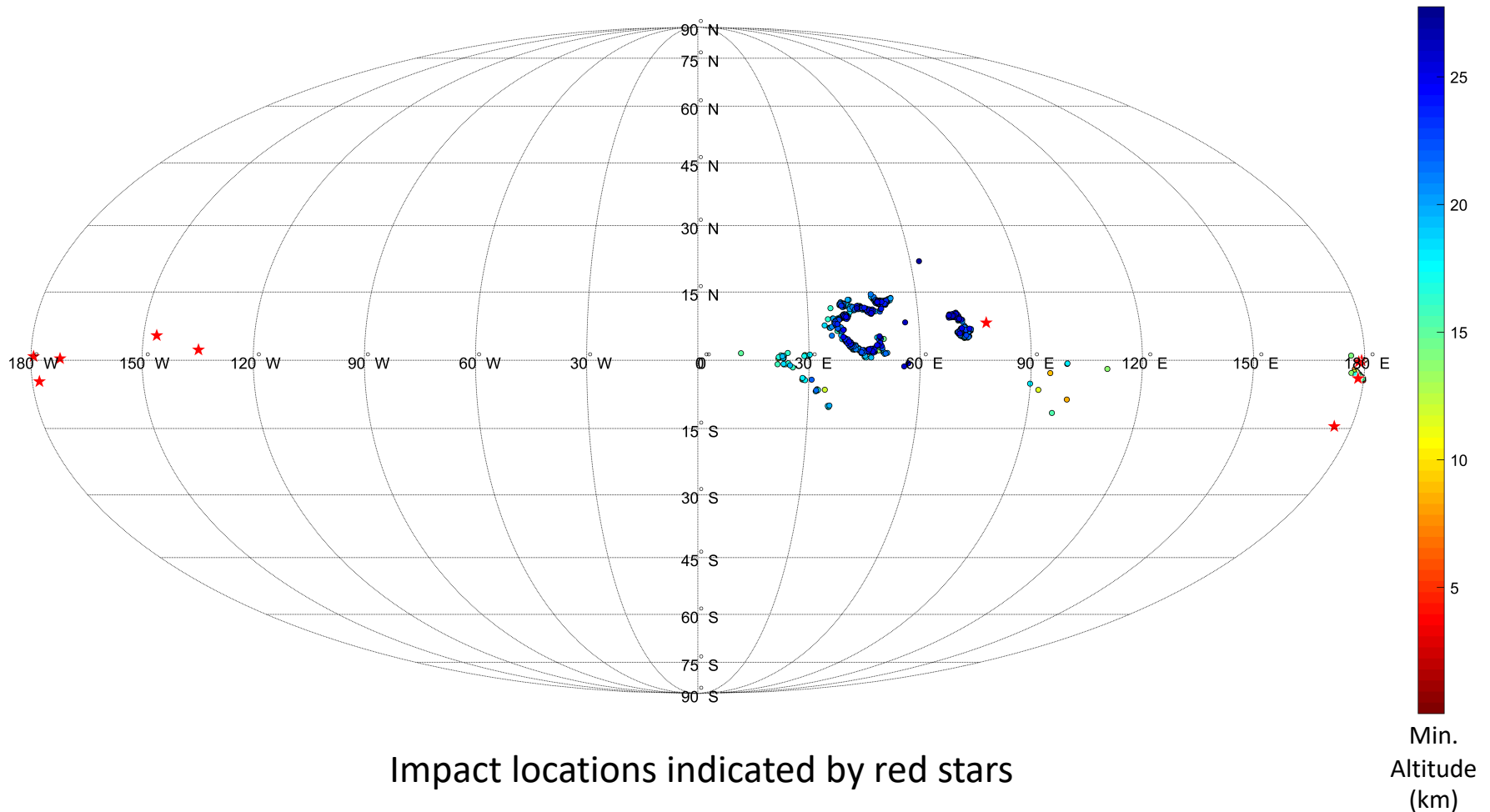
None of the 1,150 samples impact Ceres within 20 years

50-year Monte Carlo Study



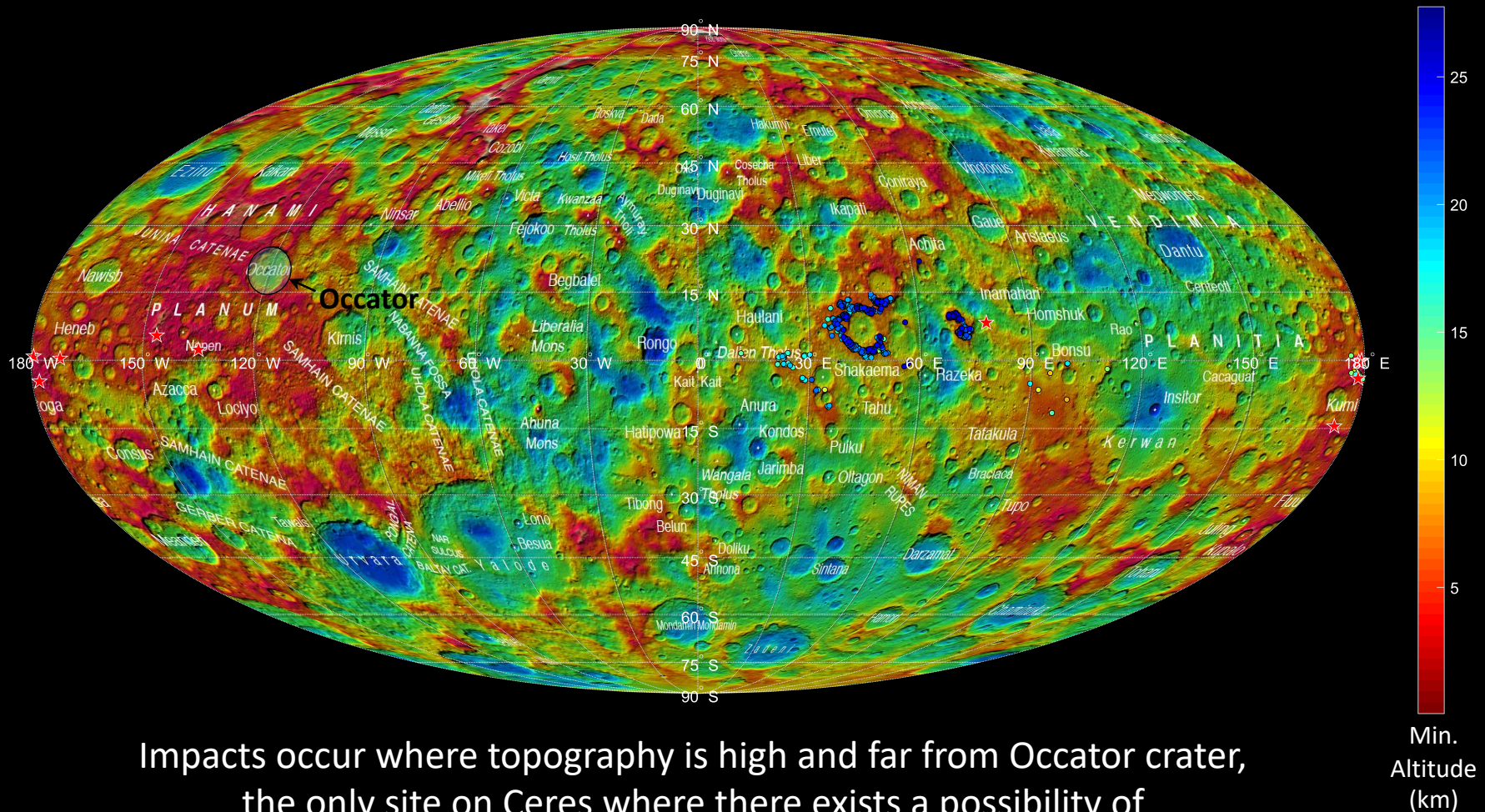
99.1% of samples do not impact Ceres in 50 years

Location of Minimum Altitude and Unlikely Impact Sites for 50-yr Monte Carlo Study



Location of Minimum Altitude and Unlikely Impact Sites for 50-yr Monte Carlo Study

with Ceres relative topography (red = high, blue = low)



Impacts occur where topography is high and far from Occator crater, the only site on Ceres where there exists a possibility of contamination reaching subsurface liquid

Summary

- Monte Carlo analysis for end-of-mission orbit confirms spacecraft will not impact Ceres for greater than 20 years
- Dawn is in compliance with Ceres orbital lifetime requirement of greater than 20 years based on Project's worst-case credible Ceres gravity field
- 99% confidence orbital lifetime exceeds 50 years
- PP report written and sent to NASA HQ in April
- Spacecraft arrived at XMO7 early June, anticipated end-of-mission October this year
- Present-day trajectory predictions well within bounds of Monte Carlo study (~ 0.1 -sigma)

The Dawn Project is in compliance with Ceres planetary protection requirements and guidelines